February 14, 1861.

Major-General SABINE, R.A., Treasurer and Vice-President, in the Chair.

The following communication was read :—

"On Magnetic Storms and Earth-Currents." By CHARLES V. WALKER, Esq., F.R.S., F.R.A.S. Received Jan. 31, 1861.

(Abstract.)

The author first refers to the movements of telegraph needles, due to causes external to the apparatus itself, which were noticed very soon after the first electric telegraphs were erected. In illustration, he gives some extracts from his diary at various dates in the year 1847; and a copy of a General Order which he issued on the 25th of October in that year, calling upon the telegraph clerks under his charge in the south-eastern district of England to take notes of these phenomena, and forward them to his office. The telegraph in use there then, as well as now, is Cooke and Wheatstone's needle instrument, having one or two vertical galvanometers.

He makes some extracts from his 'Electric Telegraph Manipulation,' published in 1850, showing that the impression expressed in the extracts from his diary, of a connexion between auroral manifestations and the phenomena in question, was confirmed. And he refers back to the published account of 'The daily Observations of Magnetometers at the Royal Observatory, Greenwich, in the year 1847,' and extracts from it the reports made of the behaviour of the magnetometers on the days cited, showing that they were very much disturbed.

The author describes the time in question as a period of great disturbance; so much so, that in the year 1848 he was constrained to adopt a device by means of which the telegraph communication might be carried on, notwithstanding the presence of these foreign influences in the wires. But his plans were hardly matured and in operation before the cause disappeared; the disturbances almost entirely ceased. The years 1847 and 1848 had been periods of great activity. The year 1849 was a period almost of inaction; and this

continued, a circumstance which, although it caused at the time some surprise, tended to withdraw attention from the question.

A paper by Mr. W. H. Barlow is then referred to, which was read before the Royal Society on May 25, 1848, and subsequently published in the 'Philosophical Transactions;' and in which a very interesting set of observations are given, made at Derby in May 1848, upon various lines of telegraph centring in that city. The relative bearing of the terminal stations, and not the route of the wires, is at the basis of these observations; and it is considered that the wires conveyed a portion of a terrestrial current of electricity, which current appeared to travel between S. 28° W. and S. 75° W.

The author goes on to state that, after a comparatively long lull, with only here and there a sign of moderate activity, attention was again called to these earth-currents about the year 1856; and more definite instructions were issued for observations to be made, and returns sent in, which has led to a large accumulation of observations, commencing early in 1857. It is not his purpose to discuss the mass of observations, nor to extract from them the dates of great disturbance; for this would only go to show the general relation between earth-current, magnetic disturbance, and aurora, which is already well established.

The most notable period of disturbance that has occurred since electric telegraphs have been in existence, was from August 27th to September 6th, 1859. It was recognized in one or more of its modes of manifestation, not only in Europe and America, but in Australia. Notices of the phenomena, collected in all parts of the world, are given by Prof. Elias Loomis in the 'American Journal of Science and Arts,' and occupy ninety-three pages. Two articles in 'Les Archives des Sciences Physiques,' by Prof. De la Rive, are also referred to. Referring to the reports in question, it was evident to the author that those who, like himself, had electric telegraphs under their control, had, to a certain extent, failed in their duty. He had, it is true, collected many observations, but they had been neither discussed nor published; and M. De la Rive had to express his regret that the returns which reached him of this great storm gave him no clue as to the direction of the currents; and for lack of this information the conclusions to which he arrived admit of reconsideration. Mr. Walker, upon learning this, took the matter up more actively.

The south-eastern district, where the observations were made, is shown by the Map which accompanies this communication, and may be regarded as bounded N. by the Thames, E. and S. by the British Channel, and W. by the other southern counties of England. Kent, Surrey, Sussex, and Berkshire, are concerned in contributing to the observations. Eighteen pairs of terminal stations have been selected; the eighteen direct lines, drawn to connect each pair of stations, make different angles with the magnetic meridian. The view taken by the author is that a flood or stream of electricity, of indefinite width, is drifting across the country, and that portions of it appear as derived currents in the telegraph wires, entering by the earth connexion at one terminus, and leaving by like means at the other. The derived current enters at the terminus nearest to the point of the horizon *from* which the main current flows, and leaves at that nearest the point *toward* which it flows.

A Table is then given of the eighteen pairs of stations, their names, the angle their joining line makes with the magnetic meridian, the direct distance from station to station, and the distance by the wire route.

The returns made of the August-September storm of 1859 are more meagre than usual, for reasons that are given; and the author explains, that on the very days when the clerks would be most valuable as observers, they are more occupied in their ordinary duties from the presence of the disturbances, which harass them in their work; and on this account he expresses himself the more indebted to those who have observed so well at such times, especially to Messrs. J. Dyke, D. Malpas, and T. Pulley.

An extract is next given from the last Report of the Astronomer Royal to the Board of Visitors, stating that he cannot extract from the returns made by telegraph clerks an idea of the phases of earth-currents, to make them comparable with those of magnetic storms. Into these views Mr. Walker enters; and while pleading guilty to not having contributed from his district any observations to the Royal Observatory, he explains that it is because he had not heretofore had the opportunity of subjecting what he had collected to anything like a fair discussion. But he quite agrees with the Astronomer Royal, in thinking that it may turn out to be desirable that observations of earth-currents should be made in a magnetic

observatory, side by side with those of the magnetometers, on wires specially erected; which wires, as appears from the sequel, need not be of any great length; for the Margate-Ramsgate group, three miles in length, is found to be very active, and action has been found on a length of 972 yards.

Reports are then given of the behaviour of the needles during the August-September storm of 1859, followed by a Table containing a series of consecutive observations which the Ramsgate clerk made from August 29th to September 2nd, and which show the duration and changes of the currents, the *general* direction in which they were moving, and their comparative values; details which were wanting to M. De la Rive when he wrote on this storm.

The author adverts to the remarkable manner in which the change from a current in one direction to a current in another is brought about, by no drift of anything like a "circular storm," nor by any kind of axial rotation; and in contrast to the calm minutes in the midst of an active period, he cites cases of activity, which are common enough in periods otherwise calm. He shows also how the value of the derived current varies with the size of the wire.

Passing from this more general view, he describes the arrangement made for forming a more definite opinion of the value of the currents collected, and how he proposed to turn to better account the next storm-days, of which some good cases followed on August 8 to 12 inclusive, and on Sept. 7, 1860, which is the last storm-day that has occurred. On the days in question a good series of observations were made, the results of which are given in Tables which accompany the communication. These Tables are discussed, and the values of the currents of either kind are given in detail in degrees and in time; and the means are deduced. Before discussing the results, the author takes occasion to call attention to the very active habit of the Margate-Ramsgate line, and to the high value of the currents collected there, although, as before stated, its length is only three miles.

On discussing the Tables, it appears that 1 current in 20 had a duration of less than half a minute. The proportion of currents above and below 5 minutes' duration was as 1 to 2·32. Of those above 20 minutes and those between 5 minutes and 20 minutes, the proportion was as 1 to 3·8. The 1-minute currents are most in number; then, in order, the 2-min., 3-min., 4-min., ½-min. and

5-min. The observations, which embraced a period of 50 hours 42 minutes, show very nearly an equal duration of N. and S. currents, the difference being $21\frac{1}{2}$ minutes in favour of the S. currents. The mean duration of N. currents was 9·51 min.; of S., 9·42 min. The proportion of currents exceeding 45° in value to those below 45°, was as 1 to 6·49. The 15° to 20° currents are most in number; then follow, in order, the 5° to 10°; then the 10° to 15°. The mean value of the N. currents was 28°·01; of the S., 26°·07.

Mr. Walker then refers to the opinion of M. De la Rive, that the S. currents are merely due to the secondary polarities acquired by the earth-plates, and shows that it is not in accordance with the facts here accumulated; for, from the results given, it would be hard to say that either the N. or the S. currents exceed the other in value; and no one thing could here be said of the N. currents, which might not, with equal truth and equal force, be said of the S. currents.

The remarks thus far have reference to a solitary telegraph group, from which the *general* drift, but not the *special* direction of the earth-currents, is gathered. The action produced might be equally due to a current running in a direction many degrees to the right or many degrees to the left of the direct line joining the two stations. In illustration of this, a series of diagrams have been prepared, in the first of which the lines of direction (referred to the magnetic meridian) of all the telegraph groups are set off; in others, the lines alone on which observations were made at a given time, are laid down. In proportion as the two boundary lines in any case make a greater angle with each other, the absolute direction of the current is more nearly determined. Cases are given and discussed, and the conclusions progressively arrived at, in order, as lines with a greater angle occur, to give the dimensions and position of the arc of the horizon within which the resultant line of direction is situated. When observations are obtained from only one line, the resultant is known to be somewhere in one half of the horizon; but the place is not proximately defined. Frequent observations were made on a pair of lines making an angle with each other of 74°. This reduced the limit within which the resultant was to be sought to 106°. Other observations were made on a pair of lines making an angle of 136°, which reduced the limit to 42°. And finally, a table of observations is given, which were made upon a pair of lines making an angle

of 147°, which reduces the arc within which the resultant is to be sought to 31°; and this is the closest result that has yet come out from absolute observation. This arc is within the limits of each of the larger arcs that come out from the previous observations, and it extends from 46° to 77° E. of the magnetic north.

The currents in all the cases cited were not confined to the limiting lines, but were constantly found in one or more of the intermediate lines, and always in a direction consistent with the view taken. In the last case, where the arc is reduced to 31°, and in most of the observations tabulated, the current in the limiting lines was so strong that the author felt himself fully justified in concluding that if he had lines of telegraph beyond these limiting lines, he should have found currents: he has assumed 10° as not likely to be beyond the range; and this reduces the arc to 11°; and knowing from experience in which limiting line the current is apt to be more active, he has divided the arc of 11° into the proportion of 7° to 4°; and has set off a line, which may be taken to be a very close approximation to the direction in which the currents move. It falls 63° E. of magnetic N.; and by deducting from this $21\frac{1}{4}°$, the value taken for magnetic declination, the direction of the earth-currents, referred to the astronomical meridian, is $41\frac{3}{4}°$ E. of N., or N.E. within $3\frac{1}{4}°$. When the currents change in direction, it becomes S.W. within $3\frac{1}{4}°$. The cases discussed go back as far as 1857; and there appears to have been the same general direction during that period. A N.W. and S.E. direction for the resultant is not known.

The author discusses, as well as he can from the few data before him, a few observations made in France and Switzerland. They are meagre in detail, but confirm the impression, which would naturally arise, that some such general direction will be found there. He also refers back to Mr. Barlow's paper, in which an arc of 47° was obtained, and within which the N.E. bearing was situated, being 30° from one limit of the arc and 17° from the other; showing that from the year 1848 to the present time no great change in azimuth has taken place.

A few remarks follow in explanation of certain specialities and anomalies in the behaviour of some of the lines in respect to their azimuths, and on the relative conductive power of the various geological strata concerned. And the author thinks it very probable that many of the currents, observed some thirty years ago in the metal-

liferous veins in Cornwall, may have been veritable earth-currents, and may have been coincident with magnetic storms.

Having determined the proximate direction of earth-currents, Mr. Walker referred to the magnetometers of an observatory merely as magnets, in order to discover whether the magnetic disturbances at a given time were in accordance with the known reaction of electric currents and magnets. The Astronomer Royal, as well as General Sabine, furnished him with the photograms from Greenwich and Kew respectively, which he required for making the comparisons. He has selected some cases of earth-currents, and has set them out in curves, side by side with the Greenwich or Kew curves, and has found a sufficient amount of coincidence to confirm the conclusion that arises, and to encourage further inquiries. He has laid down the position which the declinometer and the horizontal-force magnetometer would tend merely as magnets to assume under the influence of currents moving in the assigned direction, and has given some extracts from the Greenwich observations in support of the views he takes.

The author has made no attempt to trace the origin of the currents in question. He simply takes them as he finds them, and endeavours to arrange them in some degree of order; and he touches very lightly upon terrestrial magnetism itself. He considers that, "although we are considerably in the dark as to the forms of force in operation to make up the *whole* of the causes concerned in magnetic disturbance, we are yet quite certain that the current form of force is at least in *part* concerned." And he adds, "We can collect this force and measure it, and deal with it independently. We can receive the results and record them photographically as foreshadowed by the Astronomer Royal, side by side with those of the magnetometers. And doubtless should such combined results come at any future day under discussion—and more so, should they pass into the hands of General Sabine,—a method would be devised of eliminating the value due to these known causes, that is, due to earth-currents absolutely collected, and thereby rendering the value thus corrected more manageable; and we might get one step nearer towards penetrating into the more recondite causes of the earth's magnetism and its variations." And this cannot be accomplished until Mr. Airy's suggestion, of including the earth-currents in the observations of a magnetic observatory, is realized.